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PESTICIDES AND SOIL FAUNA

by

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The study of the soil fauna has been a long neglected field of zoology. With the exception of earthworms little was known about the animal life in the soil up to the first decades of this age. Obstacles for study of the soil animals were the hidden way of life, the complexity of the substrate and the difficulty to collect the animals quantitatively. Since then a number of collecting methods has been developed and most groups can now be studied quantitatively in the most varying substrates.

The composition of the soil fauna is extremely varied. Nearly all phyla of the Animal Kingdom are represented and the species range in size from a hundredth of a mm to the tenthousend fold of this. Many groups, especially the smaller ones are still unsufficiently known and much taxonomical work remains to be done.

However, thanks to a still increasing number of researchers, we get now a rough insight in the role of different groups. Several groups — millipedes, dipteralarvae, collemboles and oribatid mites — have an important function in the decomposition of organic matter in the soil, either by diminution of litter or by interacting with decomposing micro-organisms. Earthworms and enchytraeids are mainly important by tunneling or transporting activities, thus improving the soil structure.

Other groups as nematods and several insect larvae interfere with cultivated plants and may cause much trouble in agriculture and forestry. A last important group is formed by the predators, part of which live in the soil — mesostigmatic mites and centipedes —, whereas others are active at the soil surface : carabids and spiders.

The animal community varies widely in different types of cultures. In forest soils species composition and biomass is generally much richer than in grassland and orchards. In arable soils climatic conditions and culture measures are the main causes for a still less varied composition and a much smaller biomass.

From the beginning of the application of synthetic organic insecticides against pests, researchers have been concerned about

the side effect on the soil fauna. A number of studies have been made both in the field and in laborator yexperiments. Satchell reviewed in 1955 the literature upto that time on the effects of BHC, DDT and parathion on the soil fauna. His conclusion was that where BHC and DDT dusts have been used at normal field rates there was no evidence of wholesale and permanent destruction of the soil fauna. When formulated as sprays these substances produced higher mortalities. He noted also the frequency with which the application of an insecticide is followed by an increase in a section of the soil fauna and stressed the need for further study of the long term effects of stable insecticides on the soil fauna. In 1964 Bauer gave a detailed review on studies about side effects by chlorinated hydrocarbons, organophosphorous compounds, carbamates and some herbicides on the soil fauna.

In this report mainly studies appeared since that time will be treated. At first field studies in arable land, horticultural soils, grassland, orchards and woodlands will be reviewed. Then some mechanisms which protect animal populations in the soil will be discussed. At last the impact on the ecosystem by storage of toxicants in soil animals will be considered.

Arable land

Griffith, Raw and Lofty (1967) studied the effect of five organophosphorous insecticides and three chlorinated hydrocarbons in normal field rates on the soil fauna. Samples were taken four weeks after treatment for direct effects and after 13 months for residual effects. At 1.7 kg a.i./ha none of the organophosphorous compounds had as great an effect on wireworms as an aldrin spray or a dieldrin seed dressing both at 2.5 kg/ha.

Some treatments significantly increased and some significantly decreased numbers of mites and collemboles. In general the numbers of each of the lumbricid species did not change significantly. Pitfall traps were used to find out possible changes in the surface fauna. Only tipulids were reduced in the first year and in the carabids only one species decreased. Inadequate mixing of insecticide with soil in the field and failure to penetrate deeply are stated to account for the small effects on soil fauna.

Edwards, Dennis and Empson (1967) studied the influence of DDT and aldrin at rates of 12.5 and 4.7 kg/ha respectively. Lumbricids, enchytraeids and nematods were not affected. Pauropods and symphylids were reduced, but perhaps more important is the reduction in the numbers of predacious mites by DDT. This may be the cause of the increase of the isotomid collemboles, which are not affected directly by DDT. Also the Onychiuridae were not affected significantly. A possible reason may be a repellent working

on these springtails (see below). A significant decrease was stated in Diptera larvae, part of which was injurious. The authors converted these numbers into weights of pests, predators and beneficial, i.e. saprophagous species, and expressed these in percentages of the weights of these groups in the untreated area. Predators were influenced by DDT to the same extent as pests species, though separate groups showed differences : Acari and Coleoptera were much more influenced as Chilopoda and Diptera. Aldrin did decrease predators more than pests. Saprophagous species were only slightly decreased by DDT and to the same extent as pests species by aldrin.

Influence of organochlorine insecticides on the soil fauna in arable land was also studied by Fox, Chisholm and Stewart (1964), Long, Anderson, Isa and Kyle (1967) and Burnett (1968). In all studies a decrease in soil fauna populations was found but generally resurgence was observed. However restoration of mite or collembolan numbers does not mean an unchanged composition of these microarthropods. Van de Bund (1965) studied the microarthropod fauna in plots where during 10 years DDT, lindane and parathion had been applied. The total numbers of mites in the treated plots differed only slightly from the numbers in the control plot. Collembola decreased in lindane- and parathion-treated plots but increased considerably in DDT plots. In the treated plots, both in mites and in collemboles the average number of species per sample was reduced. This points to an impoverishment of the microarthropod fauna after a long continued application of insecticides.

Organophosphorous insecticides, as being less persistant than chlorinated hydrocarbons, were also studied with respect to their influence on soil fauna. Edwards, Thompson and Beyron (1968) investigated the effect of chlorfenvinphos. Populations of microarthropods were affected in various ways even after disappearance of the residues of the insecticide.

Earthworms, especially the surface dwelling forms were much influenced. It must be noted that in experiments in boxes, the earthworms were not influenced by chlorfenvinphos, a warning not to rely too much on experiments in confined spaces. Soil-applied systemic insecticides were studied by Way and Scopes (1968). Phorate at 250 ppm killed almost all earthworms, collembola, mites and even nematodes and protozoa locally. Collembola and mites were even strongly reduced at 10 ppm. When the residue had decreased to about 2 ppm the microarthropod populations began to increase and after 15 months they were similar to those in untreated plots. Menazon and thionazin had a less pronounced effect. Also Abdellatif and Reynolds (1967) found severe toxic effects of

granulated disulfoton on soil microarthropods but after 2 months populations began to restore again.

Modern agriculture includes application of a variety of herbicides. Uptill now no influences on the soil fauna could be stated with MCPA, 2,4-D and DNOC (Rapoport and Cangioli 1963, Davis 1965, Bieringer, 1968). Karg (1965) studied in much detail the effect of DNOC on the soil microarthropods. After an initial decrease the microarthropod numbers recovered and even increased. However, it is known from own experience that in certain circumstances DNOC can be very injurious for earthworms (Van der Drift 1963).

Horticulture

The effect of different methods of soil sterilization (steam, chloropicrin, formalin) may cause high mortality in all groups of animals. Dependent on possibilities for immigration from deeper soil layers and adjoining not treated plots or from added stable manure the population may recover (Blankwaardt and Van der Drift 1961).

Heungens (1969) found that heavy treatments of potsoils with aldrin, carbaryl and the nematicide DBCP caused severe decreases of earthworms but enchytraeids were unaffected. Collembola were decimated by carbaryl but increased with DBCP. The last may partly be caused by decreasing numbers of mites which are predacious on collemboles.

Soil fumigation with DD, as applied in the annual desinfection of begonia fields in the Genth area, appeared remarkably little injurious for the soil fauna. Earthworms, enchytraeids, mites and collemboles mainly live in the top 4 cm layer, where the DD action is less severe. (Van den Brande and Heungens 1969)

Grasslands and Orchards

The initial and long-term effects of chlorinated hydrocarbon insecticides and some herbicides in grassland were studied by Fox. Aldrin, dieldrin and heptachlor reduced the number of collemboles during the first year, but after two years no significant differences could be detected. DDT caused a transitory increase in collembola during two years. Though 13 years after application aldrin and chlordan could still be discovered in the soil, no significant differences with control were present in springtail populations (Fox 1967). Atrazine, monuron, dalapon, TCA and 2,4-D induced changes in several fauna groups. The data suggest that these changes were chiefly caused indirectly by the herbicides altering the floristic composition of the grassland (Fox 1964).

A great variety of pesticides — insecticides, fungicides and herbicides are applied in orchards, often with high frequency. The use of sprays results in a considerable amount of chemicals around the trees. This was stated by Stringer and Pickard (1963) in a study on the DDT content of soil and of earthworms in an apple orchard. Near the trunk the concentration of DDT was about 7 times higher than at the perimeter of the crown and in the interrows. Nevertheless the distribution of the earthworms was rather uniform. It was stated that the DDT concentration in the earthworms collected near the trunk was 2 times higher than in those collected on a distance of 2 m. at the perimeter of the crown and even 4 times higher than those collected in the interrow.

Evidently spray residues will affect the surface fauna in orchards seriously. Van Dinther (1963) ascertained the lethal doses of various insecticides for the carabid Pseudophonus rufipes (Dej.) and compared these dosages expressed in kg/ha with those normally applied for field control of noxious insects. It was found that parathion, dieldrin and sevin may have a serious effect on the Pseudophonus population and that DDT and toxaphene are less dangerous. Herne and Putman (1966) also stated the toxicity of DDT, parathion and carbaryl for most insect and arachnid predators in orchards.

The effect of organic fungicides on the soil microarthropods in orchard soil was studied by Rapoport and Sánchez (1968). Nipagin, captan, zineb and omadine did influence the microarthropod population only temporarily : no effects were detectable after 28 days.

Van Rhee (1969) pointed to the severe effect of copper oxychloride sprays on earthworm populations and found that low-volume pesticide sprayings in modern apple orchards affected earthworm numbers much less than high-volume sprayings in apple standard orchards.

Woodlands

In forest soils the numbers of microarthropods, especially oribatei is much larger than in other soil types and also the surface fauna is generally richer. Irregular distribution pattern both of soil fauna and surface fauna and the natural seasonal fluctuations in the numbers hamper the studies on the effect of insecticide treatments on soil fauna. In addition the distribution of aerially applied insecticide reaching the soil is very irregular. Giles and Peterle (1963) found that isotope labelled malathion, sprayed at 2 lb/acre did not penetrate more than four layers of dead leaves on the forest floor. No effects were observed on earthworms or

snails. Arthropod numbers were reduced, but in general recovery was rapid. In field experiments, where carbaryl was directly applied to the soil surface, Stegeman (1964) found no significant effect on mite populations. Collembola were influenced strongly but after 4 months the population recovered. Voronova (1968) also found with carbaryl a small decrease of oribatid mites, inconclusive, results with collemboles, but severe reductions of earthworms enchytraids and predacious carabids. The numbers of last three groups were very low even a year afterwards. Knight and Parker Chesson (1965) did not find serious effects of DDT on the population density of each of four families of Collembola. Byzova (1964) studied the effect of BHC and DDT treatments from airplanes against the encephalitis carrier Ixodes persulcatus P. Sch. in coniferous forests. The dosages of insecticides were high, 30 — 50 kg/ha, and the author found considerably reduced numbers of soil insects, mites and enchytraeids in the first year after treatment. Most populations were restored after 2 of 3 years but surface dwelling carabids and myriapods were practically absent in the DDT treated plots. In the plots treated with BHC saprophagous animals had increased.

From the field studies in arable land, orchards and woodlands it is clear that application of pesticides in practicable amounts influences the soil fauna. However, conclusions of these studies are sometimes contradictory. There are many reasons why the same pesticide does not affect the same species to the same degree in different cases. There may be differences in soil type and organic matter content of the soil which influences the pesticide's activity. Differences in atmospheric conditions at application time may also influence the efficacy decisively both by interfering with the chemical's activity as with the animal's activity. A third reason may be that the pesticide does not only affect the species studied but also fellow-species which may be interrelated with the first by competition or predator-prey relationship. These indirect effects generally will be different from case to case and may have an important effect on the development of the population. It seems justifiable to make the following conclusions. Herbicides and fungicides, which are designed to control weeds and fungal parasites generally affect the soil fauna only to a limited degree. Insecticides worked into the soil may have severe effects, but even with persistent insecticides the soil fauna recovers in shorter or longer time. Generally the composition of the soil fauna will be changed. Predacious mites seem to be very susceptible for DDT, contrary to collemboles, which increase possibly as a consequence of reduced predation. Sprayed insecticides which partly reach the soil surface are mainly injurious for surface dwelling species. On the whole predaceous

species, which generally have a great mobility, will have more chance to be exposed to insecticide and thus affected more seriously than sedentary saprophages, which may indeed increase.

Protecting mechanisms

Insecticides most common in soil are the persistent chlorinated hydrocarbons; Edwards (1963) calculated that one year after application 80 % of DDT may still be present. For dieldrin, lindane, chlordane, heptachlor and aldrin the percentages were 75, 60, 55, 45 and 26 respectively.

The organophosphorous compounds and the carbamates break down more rapidly and the same holds for herbicides and fungicides Measurable quantities exist in soil only for weeks or months after application. Edwards (1964) reviewed the factors that affect the persistence of insecticides in soil.

However, presence is not identical with activity. Pesticides may be adsorbed by clay minerals and by organic matter and so decrease in activity. Desorption may increase the activity again.

Harris (1966, 1967) showed that the activity of insecticides in sandy loam is higher than in clay and is least in muck. There is also a strong dependancy on moisture content : with increasing moisture content the activity is higher. In soils with a high humus content animal life is less threatened than in soils poor in humus.

Another protecting mechanism is repellency of the insecticide. Even with a most equal distribution of the chemical in the substrate there will remain, certainly for the smaller animals, uncontaminated spaces. If the animal is repelled by the chemical its change to survive will be higher. Choice experiments in petri dishes with the collembole Onychiurus have shown that this springtail is repelled by DDT (Van de Bunt 1965). In similar experiments we found aldrin and lindane to be repellent. In the case of lindane the repellency could be masked by the very quick paralyzing effect on Onychiurus. Even with higher concentrations repellency was not absolute. Animals which penetrated into the lindane area were prevented to escape by paralysis and died. This gave rise to a concentration of dead and dying animals in the repellent area. The susceptibility for a pesticide varies in different species and even within a species. Apart from physiological activity of the pesticide, susceptibility is dependent on the permeability through the integument and on elimination from and detoxication in the body. The impermeability of the animal integument for many herbicides and fungicides is perhaps the main reason why the soil fauna is not affected by these. Popp (1970) investigated the effects of dieldrin on an oribatid mite species Hermannia convexa C.L. Koch. Due to differences in permeability of the body integument the sensibility

in larvae was about 70 times and in nymphae 20 times higher than in adults. Little is known of elimination of insecticides. In Hermannia detectable amounts were present in its faeces.

One of the main causes for resistance in insects is enzymatic breakdown of the chemical. So DDT is converted by DDT dehydrochlorinase into DDE, which is not toxic for insects.

Davis (1968) studying insecticide residues in the soil macrofauna found that carabids contained practically only DDE. In earthworms and slugs only a part of the DDT was converted in DDE.

Butcher, Kirknel and Zabik (1969) demonstrated that also the springtail Folsomia candida (Willem) is capable to convert DDT into DDE. They state that the ability of these abundant and cosmopolitan animals to degrade a persistent hydrocarbon insecticide raises important questions about their role in soil decontamination.

Transfer of chlorinated hydrocarbons to the foodchain

Storage of several chlorinated hydrocarbon insecticides or their metabolites is shown in carabids, earthworms and slugs. Further research may show that in still other groups the same occurs but evidently these groups are the most important as potential food for larger predators. Davis (1968) found the residues of dieldrin and DDT and/or metabolites in carabids, collected in treated fields, to be lower than those in the respective soils. In earthworms and slugs the residues were higher than in the corresponding soils reaching values as high as 40 ppm DDT and 0.8 ppm dieldrin. Barker (1958) associated the deaths of American robins with feeding on earthworms containing 33-164 ppm DDT. So DDT concentrations of this magnitude may be a serious danger for ground feeding birds. An experimental study on the uptake of heptachlor by woodcocks via heptachlor-contaminated earthworms was made by Stickel, Hayne and Stickel (1965). Jefferies and Davis (1968) made a similar study on dieldrin and songthrushes. At the above mentioned dieldrin content of 0.8 ppm in earthworms, excretion would prevent accumulation to dangerous levels. Residues of 24.7 ppm as recorded in slugs from a strawberry field however are sufficient for the uptake of a lethal dose. As long as chlorinated hydrocarbons will be used for agricultural and medical purposes the dangers of penetrating into the above ground foodchains must be considered.

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